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SOLENOIDAL DETECTOR NOTES

HERMETICITY STUDY USING THE CCFR DATA
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Hermeticity Study using the CCFR data

Abstract

Data are used to assess the effects of dead volumes within a calorimeter system. Using data from the CCFR 28-gap $19\lambda_p$ Fe-liquid scintillator calorimeter, and by selectively removing one or more of the 28 gaps, we simulate the effects of dead space on mean pulse height, energy resolution, and fake missing E_T. We parameterize these results for easy use in specific geometries, as was done by Strovink, et al. [1]

Data sample

The data used were taken in the CCFR calorimeter, [2] and they have been made available to the community by John Yoh. Dave Bintinger has both used these data in an earlier study of energy leakage, and has made them available to us. In short, the calorimeter mass consists of 28 modules, each module consists of an Fe-scintillator-Fe sandwich, and both the Fe plates and the liquid scintillator volume are 2-inches thick. This sums to about 19 λ_p, and is therefore infinitely deep on the scale of any SSC calorimeter. The sampling frequency is a little coarse for our purposes in studying dead spaces, but it is adequate. Each liquid scintillator samples the debris from 4 inches of upstream Fe and 2 inches of scintillator, which is 0.670 λ_p or 5.90 X_0. This is uniform throughout the calorimeter except for the first scintillator layer, which samples the debris from only 2 inches of upstream Fe and 2 inches of upstream scintillator.

The CCFR data consist of measurements of pulse height in each of the 28 depth samples in this calorimeter exposed to a π^- beam at energies of 25, 50, 90, 140 and 250 GeV. There is no transverse shower information, and no transverse shower leakage in these 3 meter wide modules.

It is instructive just to look at a few events. In Figures 1(a-j) we show the pulse heights in each of the 28 layers for the first 10 π^- events from the 250 GeV run. Starting point fluctuations and depth development fluctuations are clear in these single-particle initiated showers.

Making 1 an 10 TeV jets

We construct 1 and 10 TeV "jets" by sampling events from these data sets according to a light quark fragmentation function, and summing the pedestal-subtracted ADC's. The mean "multiplicity" of each 1 TeV jet is about 12-15, which is low, since the lowest energy data set is at a beam energy of 25 GeV. Hence, the 25 GeV data set is sampled too often, that is, whenever the fragmentation

[1] M. Strovink, W. Womersley, and G. Forden, "Hermeticity in Three Cryogenic Calorimeter Geometries", Workshop on Calorimetry, U. of Alabama, 13-17 Mar 1989.

[2] F.S. Merritt, et al., NIM A245 (1986)27.

function wants a particle below 25 GeV. Single particles from these five data sets are summed until the total "beam energy" exceeds the 1 or 10 TeV requested jet energy, and only the ADC's from the last particle are scaled down to obtain the required "beam energy". The physical statistical fluctuations in the composite "jets" are correctly preserved, except for only a fraction of the last particle's energy, whose fluctuations are slightly too small for its scaled energy. Six single "jet" events are shown in Figures 2(a-f) for comparision with Figures 1. As can be seen, in our "jets" the starting point fluctuations are washed out by summing over several individual showers. This is an important difference between single hadrons and jets.

These 1 and 10 TeV "jets" are stored in the same format as the actual data, and can be read and analyzed by the same programs.

Mean Response Degradation due to Dead Space

Dead space has to start somewhere and end somewhere. Let's define the starting location of the dead space to be λ_0 and the extent of the dead space to be λ, both in units of proton absorption lengths. Since these data contain no transverse shower information, the dead space must have a width comparable to a hadronic shower. For a coil, many collaborations have decided placed it at the front of the calorimeter. For mass supports, a wide range of placements are necessary, and one often does not have a choice in where it goes. The ZEUS collaboration did a detailed study of dead space and where to put it. Their conclusion was "put it in front or put it in back, but never in the middle." This same conclusion is stated in Strovink, et al. This is an "obvious" conclusion after looking at the mean and rms fluctuations of the calorimeter response in each of the 28 gaps, displayed in Figures 3(a-b). Firstly, the rms variation is about the same order as the mean (as claimed and checked in Strovink, et al.), and the rms variations are bigger in the middle of the calorimeter.

In Figure 4 we show the mean fraction of missing energy in 250 GeV π^- showers (solid points) as a function of λ for λ_0=0. These mean values are the averages of distributions, and we show explicitly in Figure 5 those distributions for the first two points (at λ=.37 and λ=1.04). Even though the mean is small (because there are a lot of zeros due to late-interacting π's), 1% of the events loose 25% or more of their energy in the dead spaces. The same quantities are shown for 1 TeV "jets" in Figures 6 and 7, and it is apparent that the starting point fluctuations are averaged out in a multi-particle jet. At the 1% level only about 10% of the energy is missing for λ=0.37.

For dead material starting within the calorimeter volume, $\lambda_0 \neq 0$, we remove gaps starting at gap 2 for several gaps, and then starting at gap 3 for several gaps, etc. The corresponding proton absorption length depths, λ_0 and λ, are calculated from the starting gap and the number of gaps removed, respectively, and include the absorption length of the liquid scintillator. The mean fraction of energy lost as a function of λ for four values of λ_0 is shown in Figure 8 for 1 TeV "jets".

A handy formula which parameterizes the mean energy fraction lost in 1 TeV "jets", as a function of λ_0 and λ, is

$$E_{lost}/E_{total} = a_1\lambda + a_2\lambda^2 + a_3\lambda^3 \tag{0.1}$$

where the coefficients can be written as just functions of λ_0,

$$a_1 = .088 + .40\lambda_0 e^{-\lambda_0/1.2}$$

$$a_2 = .137e^{-\lambda_0/0.6} - .037$$

$$a_3 = -.02e^{-\lambda_0/0.6}$$

This formula is accurate to a few percent over the ranges $0 \le \lambda \le 3.0$ and $0 \le \lambda_0 \le 2.0$ proton absoption lengths. Usually dead material will be characterized by much smaller values of λ than 3.0, so the usefulness of this formula lies entirely at small λ, which means that the coefficient a_1 is the critical one.

Energy Resolution Degradation due to Dead Space

The same proceedure has been used for calculating the resulting energy resolution after the removal of one or more measurement gaps. We have chosen to parameterize the resolution in λ and λ_0 by parameterizing deviations from the constant "k_0" in the usual expression for the energy resolution of a calorimeter,

$$\frac{\sigma}{E} = \frac{k_0}{\sqrt{E}},$$

where "k_0" is the resolution constant for all 28 gaps, and which has a mean value near 0.90 for this particular Fe-scintillator device. This is a well-behaved calorimeter: firstly, the response at all energies is very nearly gaussian, and the energy dependence of the resolution follows $E^{-1/2}$, as shown in Figure 9. The insert shows the response of 250 GeV π^- with a gaussian fit.

These deviations are parameterized by a multiplying factor greater than 1,

$$1 + b_1\lambda + b_2\lambda^2 + b_3\lambda^3$$

where, as before, the coefficients are just functions of the starting point of the dead material, λ_0. The dependence of this resolution degradation factor ($1 + b_1\lambda + b_2\lambda^2 + b_3\lambda^3$) is shown in Figure 10 as a function of λ for four values of λ_0. We find a good representation with

$$b_1 = .175 + 6.1\lambda_0 e^{-\lambda_0/.75}$$

$$b_2 = 2.20e^{-\lambda_0/.55} + .06\lambda_0^4$$

$$b_3 = -.22b_2$$

Again, this formula is accurate to a few percent over the ranges $0 \le \lambda \le 3.0$ and $0 \le \lambda_0 \le 2.0$ proton absoption lengths. Thus, the energy resolution of a calorimeter with dead space characterized by λ and λ_0 is

$$\frac{\sigma}{E} = \frac{k_0}{\sqrt{E}}\ (1 + b_1\lambda + b_2\lambda^2 + b_3\lambda^3)$$

These are arbitrary (and funny looking) functions, but they just reproduce in a smooth way the resolution dependence in λ and λ_0, which is all we want. When plotted, the shapes of the coefficients a_i and b_i are quite similar, again leading to the rule-of-thumb that the increased rms fluctuations due to missing energy measurements are about equal to the mean missing energy.

Fake Missing E_T Rates due to Dead Space

It is easy to do a related calculation: count the number of events which have a missing energy due to dead space above a specified threshold. With the provisos that (i) the dead space is as wide as the hadronic shower, and (ii) that we are only using energy E, and not E_T, then these event rates, divided by the event sample size and multiplied by the luminosity and the physics rate for a jet of this energy, are a measure of the missing E_T trigger rates at these specified thresholds.

We show in Figures 11(a-b) these event rates divided by the sample size, i.e. we have not multiplied by the luminosity, physics rate, or included $\sin\theta$ dependence to get the true E_T rates. Also, we haven't yet parameterized these functions in λ and λ_0: we are not sure even what functional form to use. So we apologize to the reader, who has read this far, for just dumping undigested numbers on you.

Deficiencies in this Study

What we have done is simple. We have merely removed one or more measurements, and then evaluated the effects on mean missing energy and energy resolution. Dead material within a calorimeter volume, such as an aluminum coil, not only removes measurements, but as a low-Z material also buries low energy shower particles, and these particles will not reach the next measurement gap. In the end, confidence in these sorts of calculations may only come after a realistic GEANT study.

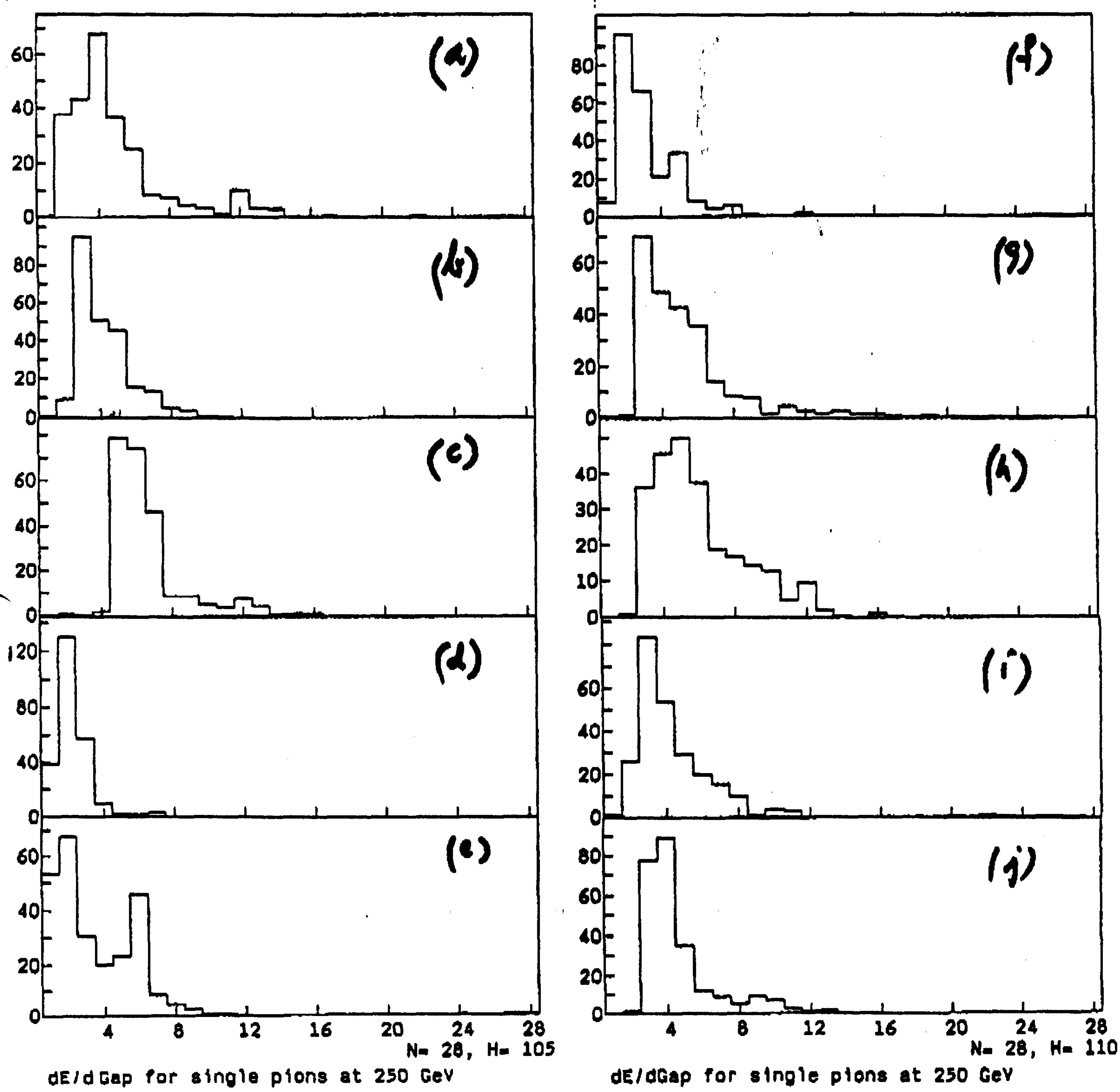

Figure 1. The individual pulse heights in each of the 28 gaps for the first ten π's at 250 GeV.

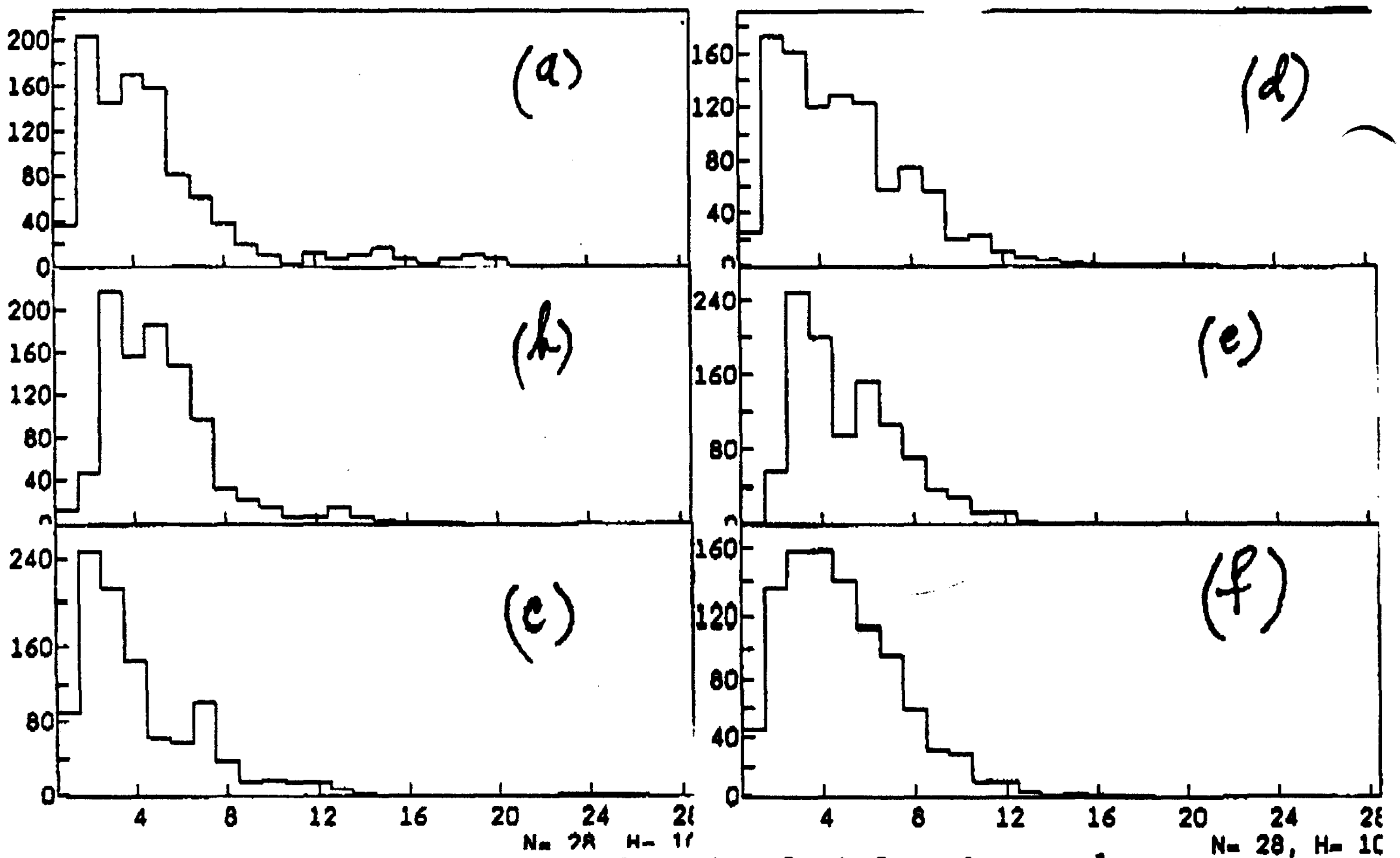

Figure 2. The individual pulse heights in each of the 28 gaps for the first six 1000 GeV "jets".

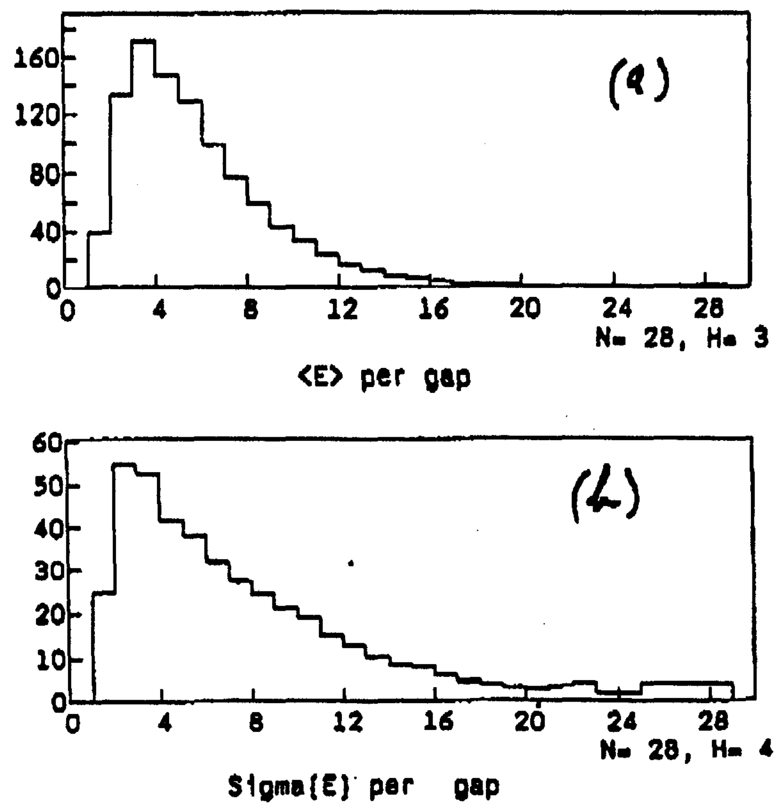

Figure 3. The mean and rms for each gap for the 1 TeV "jets".

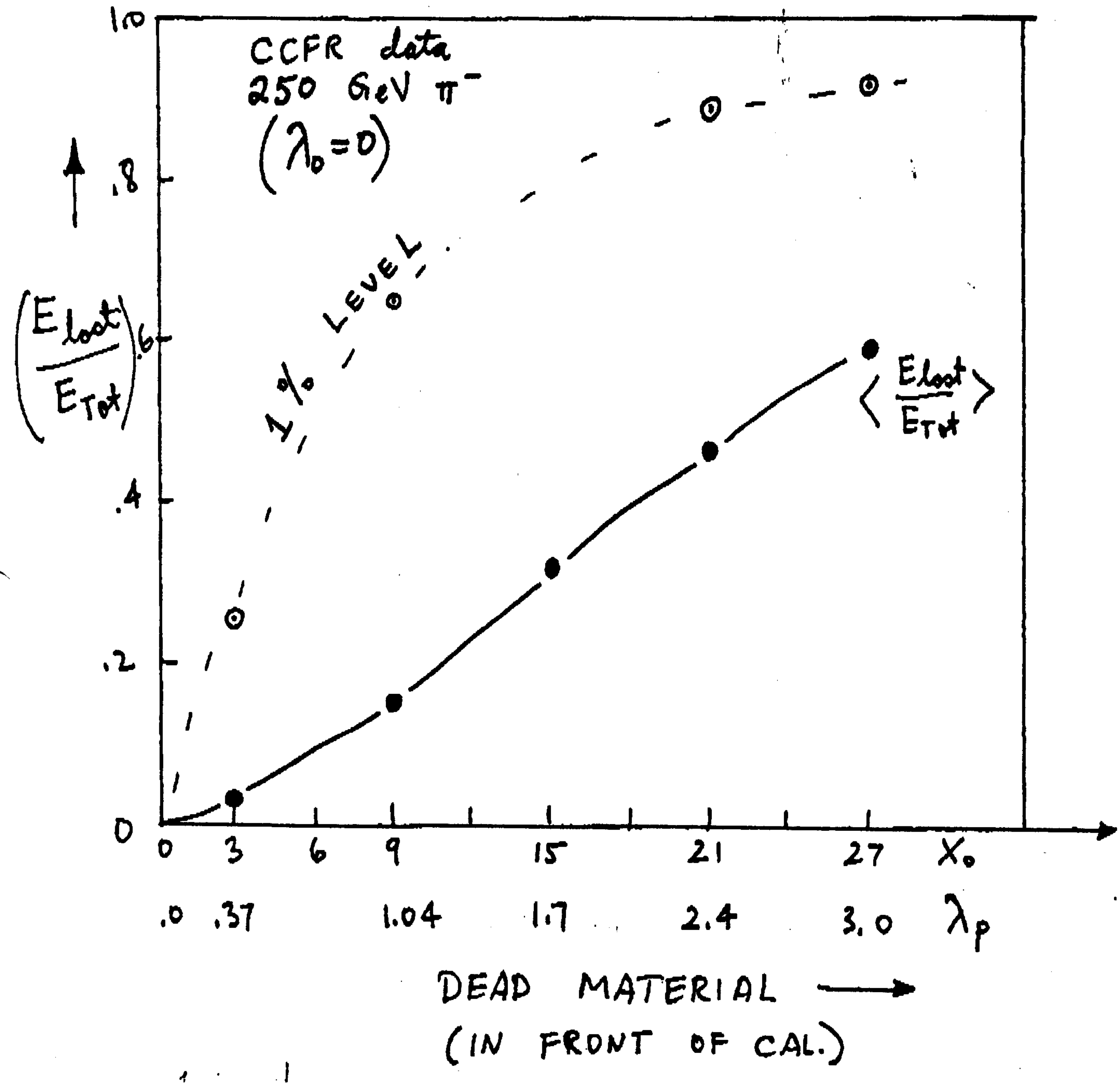

Figure 4. Mean fraction of lost energy as a function of λ and λ_0 for 250 GeV π's for $\lambda_0=0$, that is, only the first (second,third,...) measurement gap is removed.

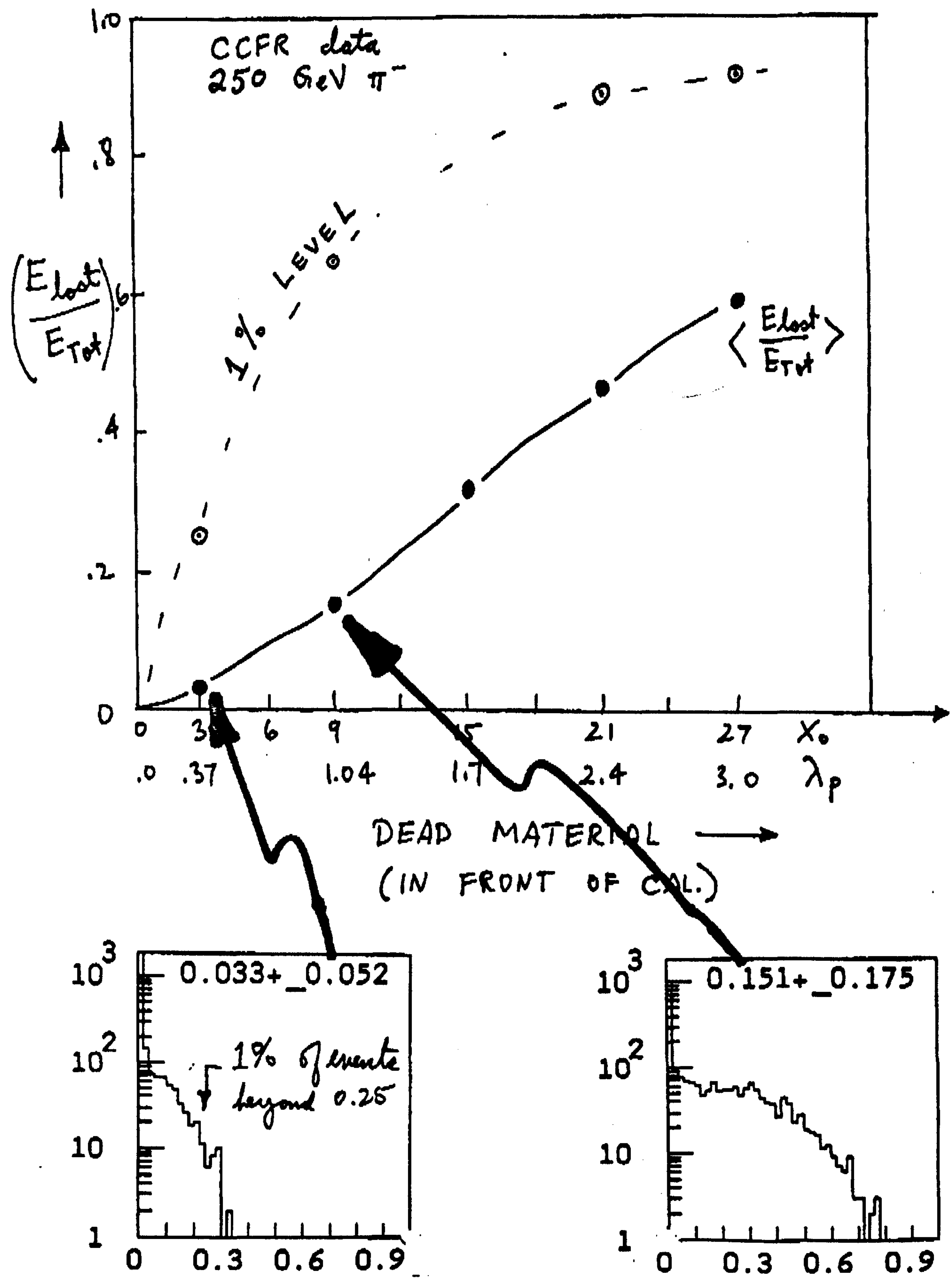

Figure 5. Same as Figure 4, but showing explicitly the distribution from which the mean is extracted.

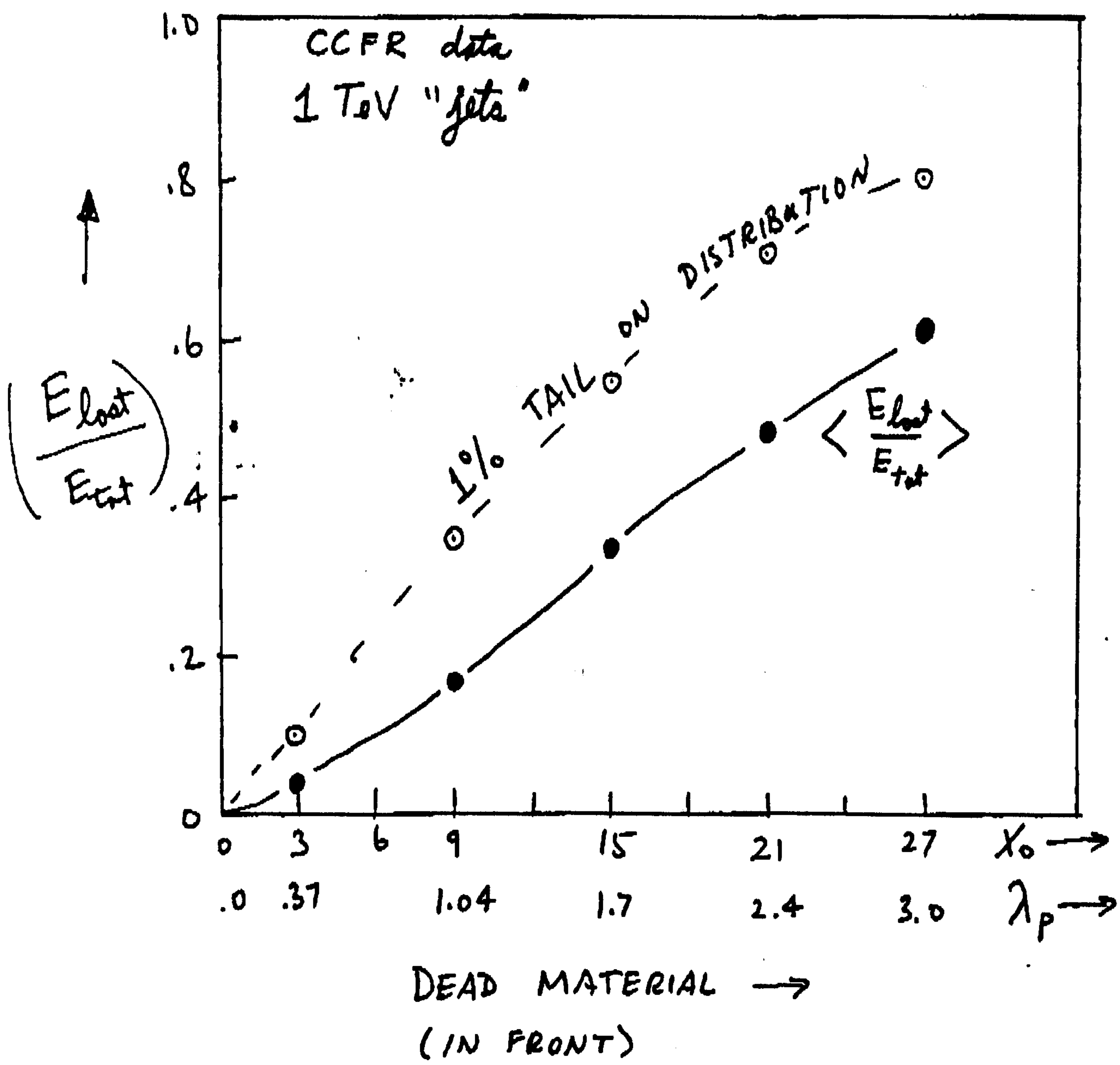

Figure 6. Same as Figure 4, but for 1 TeV "jets".

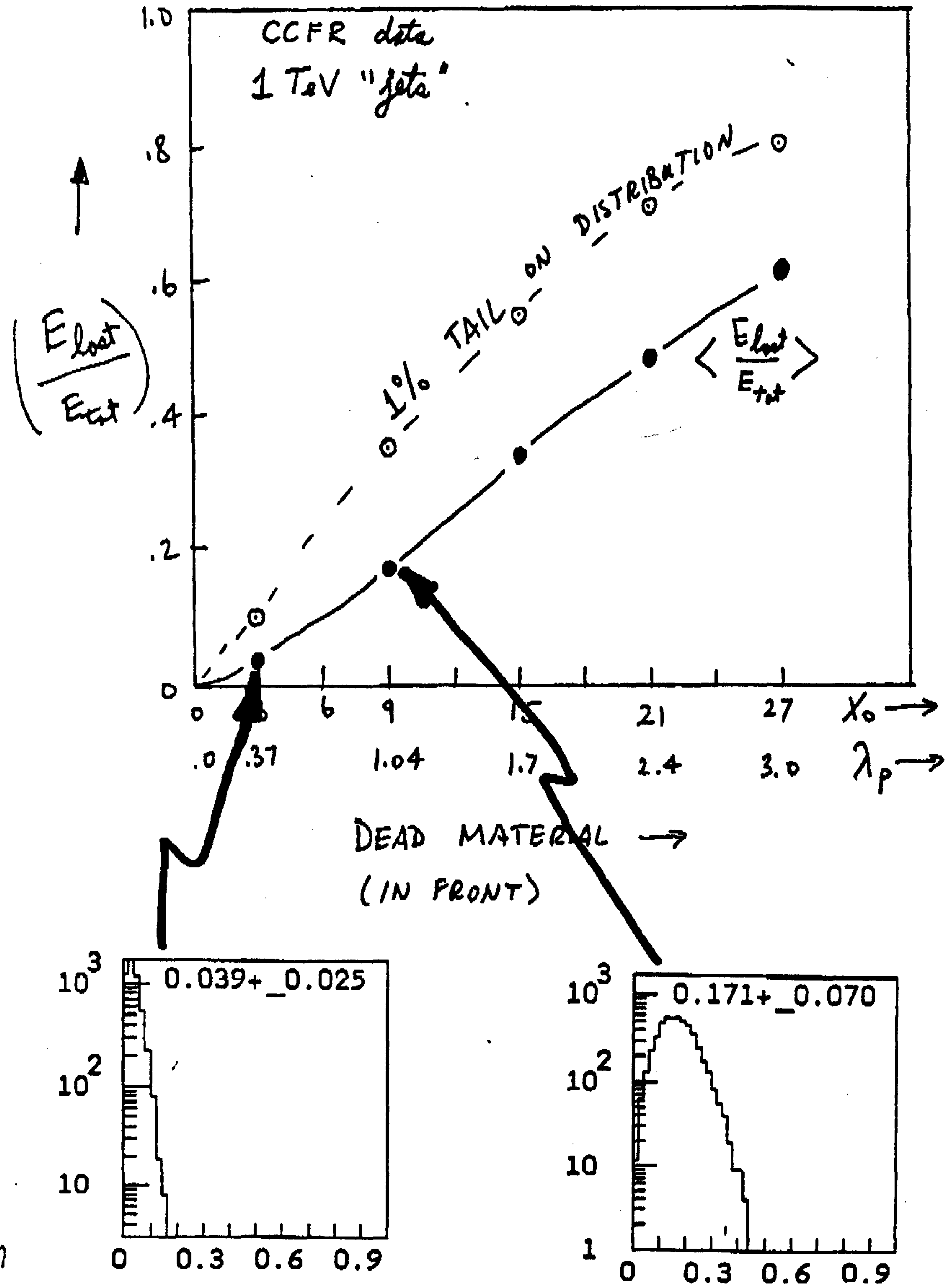

Figure 7. Same as Figure 6, but showing explicitly the distribution from which the mean is extracted.

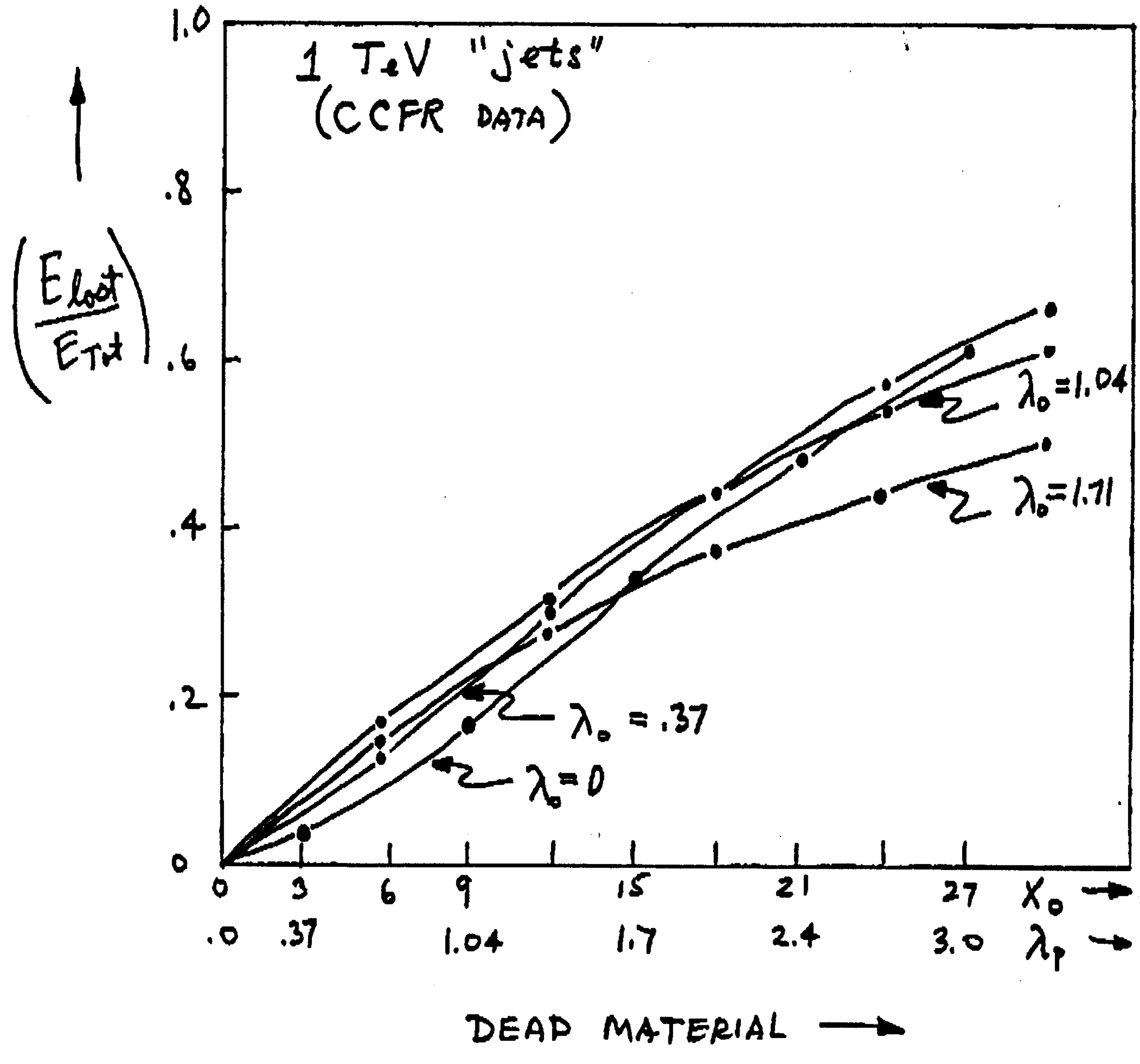

Figure 8. Mean fraction of lost energy as a function of λ and λ_0 for 1 TeV "jets".

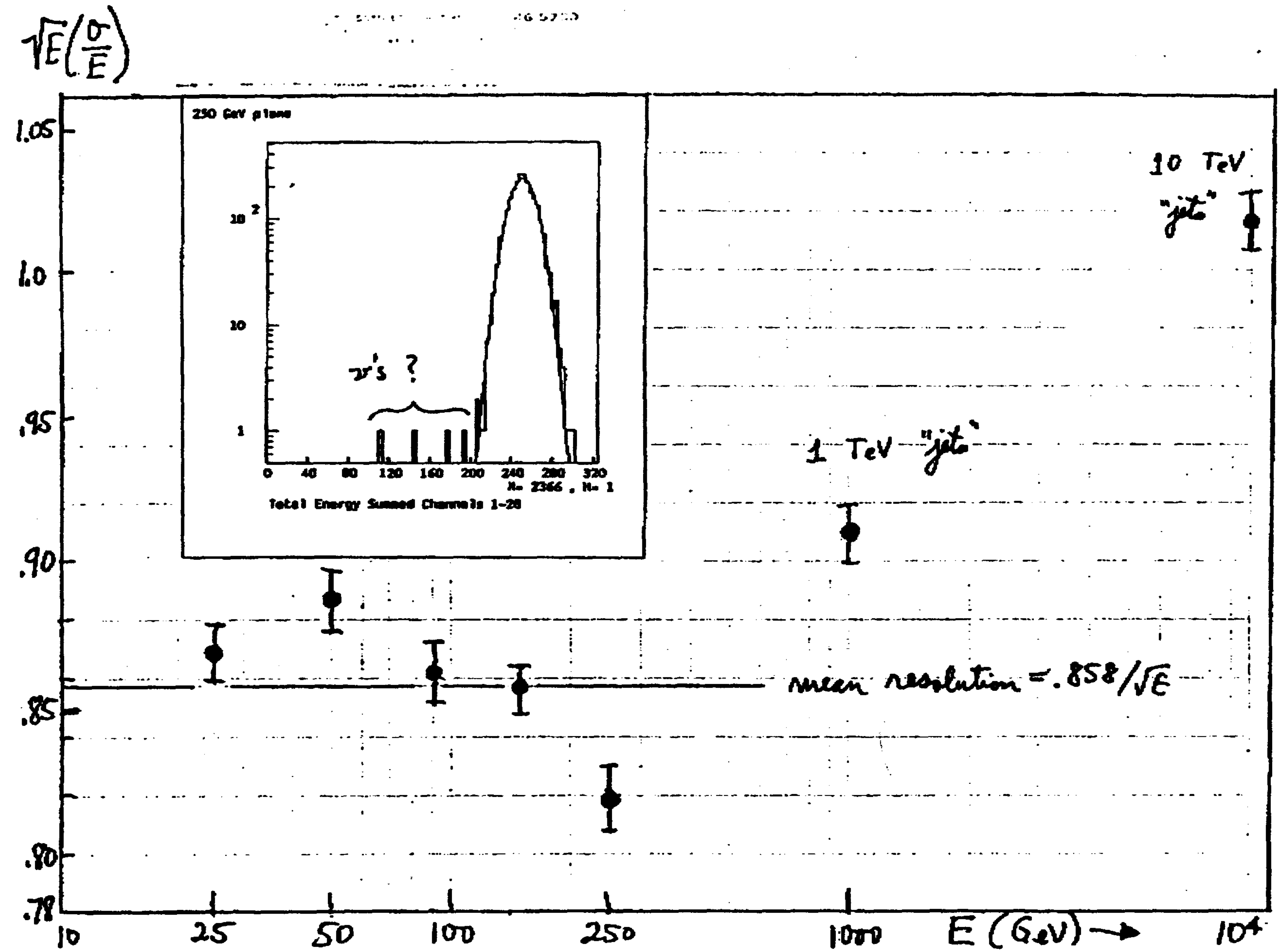

Figure 9. The energy resolution constant "k" for are the data samples at 25, 50, 90, 140, and 250 GeV, plus the constructed "jets" at 1 TeV and 10 TeV. The insert shows the pulse height distribution for the 250 GeV π^- sample, s[illegible]ing the very nice gaussian tails.

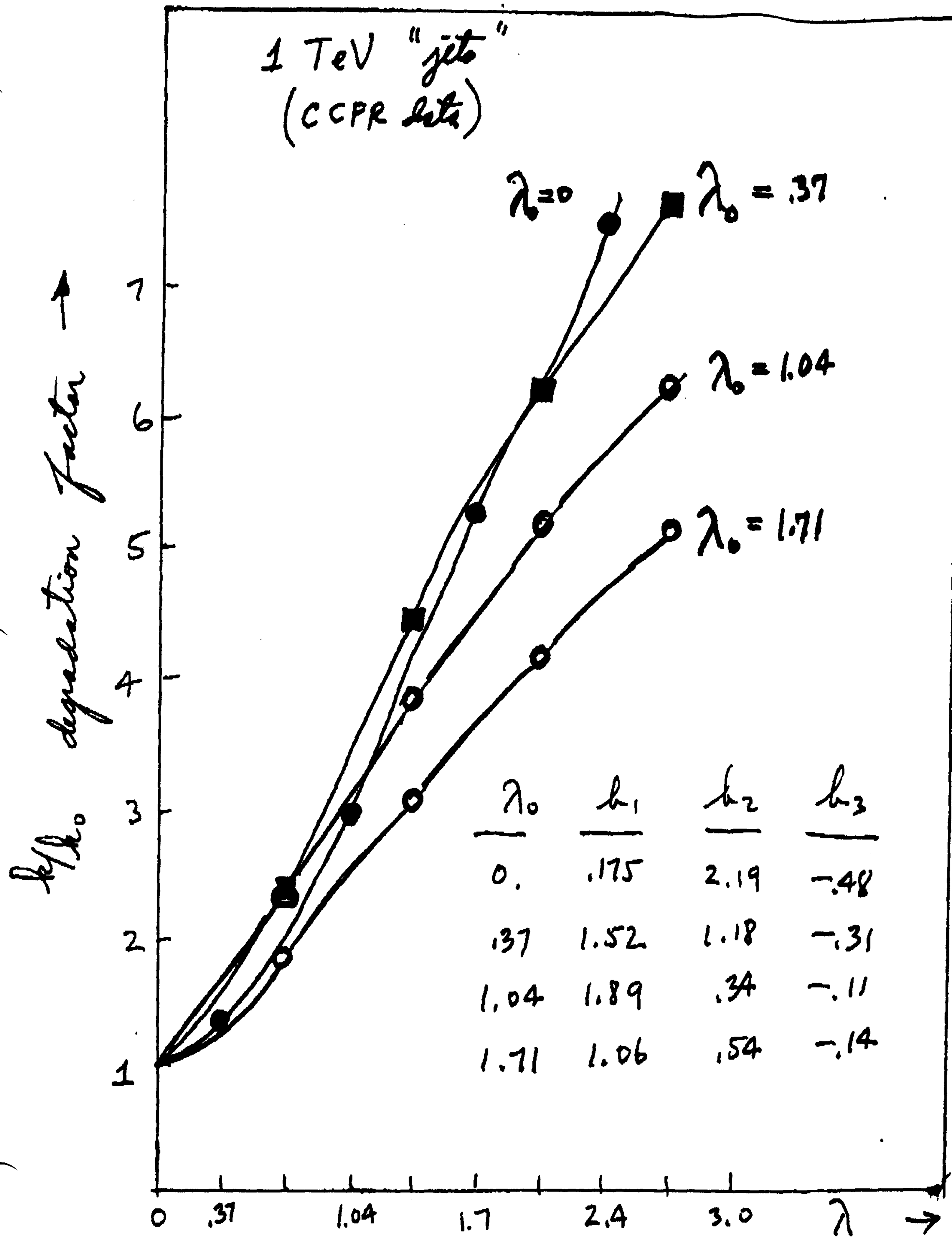

Figure 10. The multiplicitive energy resolution degradation factor as a function of λ and λ_0

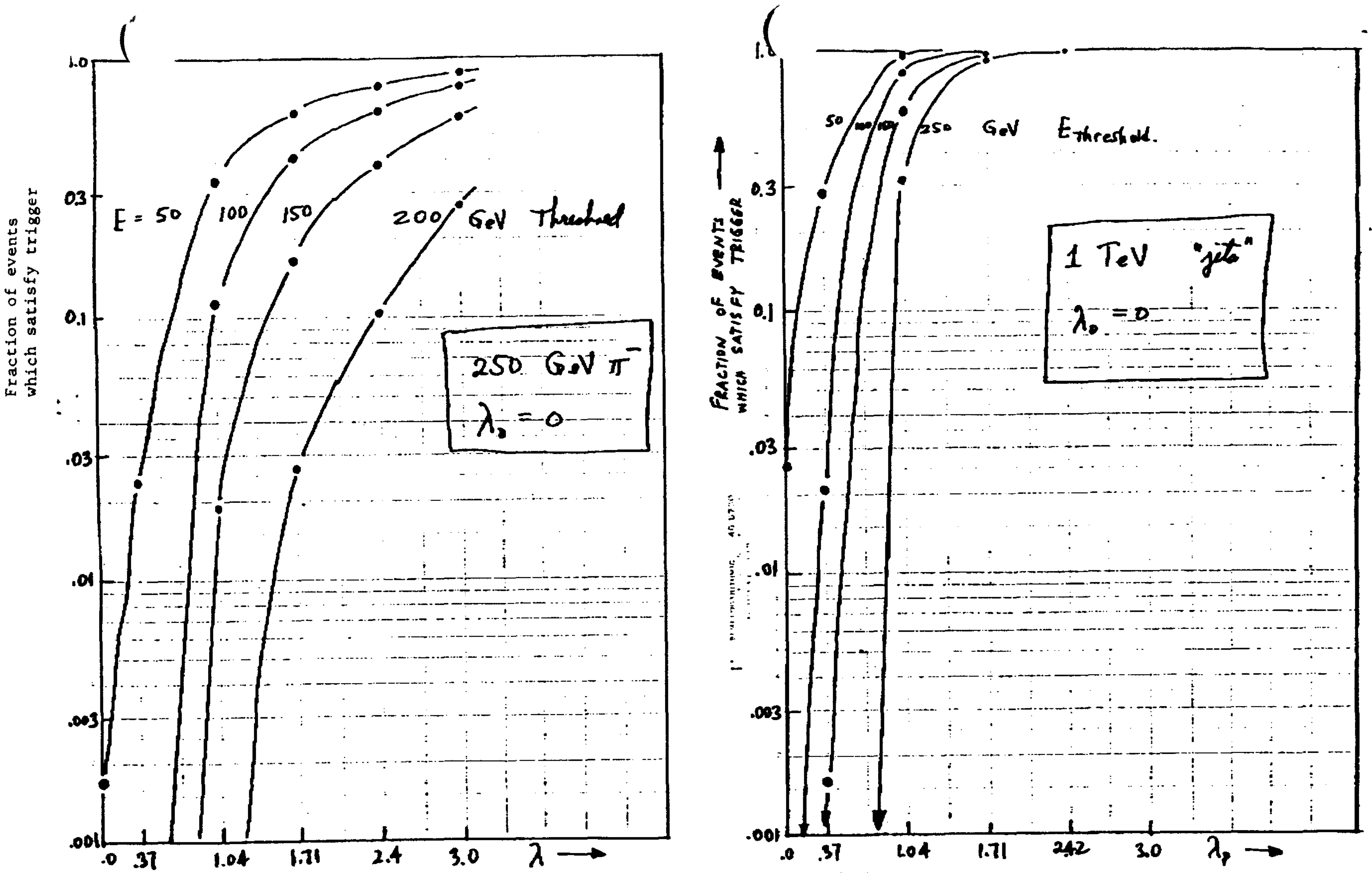

Figure 11. The fraction of events in which the missing energy exceeds a specified "trigger threshold" energy: (a) for 250 GeV π^-, (b) for 1 TeV "jets". Both plots are for λ_0=0; the λ and λ_0 dependences are not yet parameterized.